# Performance of REBAM® during ball bearing failures

The September issue of *Orbit* presented the first of a two-part article on the results of recent research on the performance of the REBAM® (Rolling Element Bearing Activity Monitor) system during natural fatigue spalling failures of rolling element bearings. The first part discussed data taken during the spalling process on a Model 214 Conrad-type deep groove ball bearing under radial loading. Article reprints are available upon request. In this, the second part, we will discuss the data taken during the spalling process on the same type of bearing under *axial* loading.

In review, the REBAM® system utilizes a high-gain eddy current proximity probe to detect small deflections in the outer ring of a bearing. The ring deflects in the target area of the probe tip when rolling elements under load pass over this location. The test rig used allowed hydraulic loading of a test bearing in either, or both, the radial and axial direction. Load was controllable from zero to 5000 pounds (22.2 kN) radially and zero to 6000 pounds (26.7 kN) axially.

The test bearing was instrumented with four REBAM® probes distributed 90 degrees apart around the outer ring of the bearing. The probes are identified as Channels 1 through 4, with Channel 1 being closest to the center of the radial load zone (11 degrees). The other three REBAM® probes are numbered sequentially in the direction opposite shaft rotation (shaft rotation was clockwise). An accelerometer was mounted near true vertical orientation on the outer surface of the test bearing housing. Figure 1 shows the layout of the REBAM® transducers and the accelerometer. The test rig was driven by a 15 horsepower AC motor equipped with a variable speed drive. For the bearing failure testing, the shaft speed was approximately 3550 rpm.

As in the radial load testing, the test

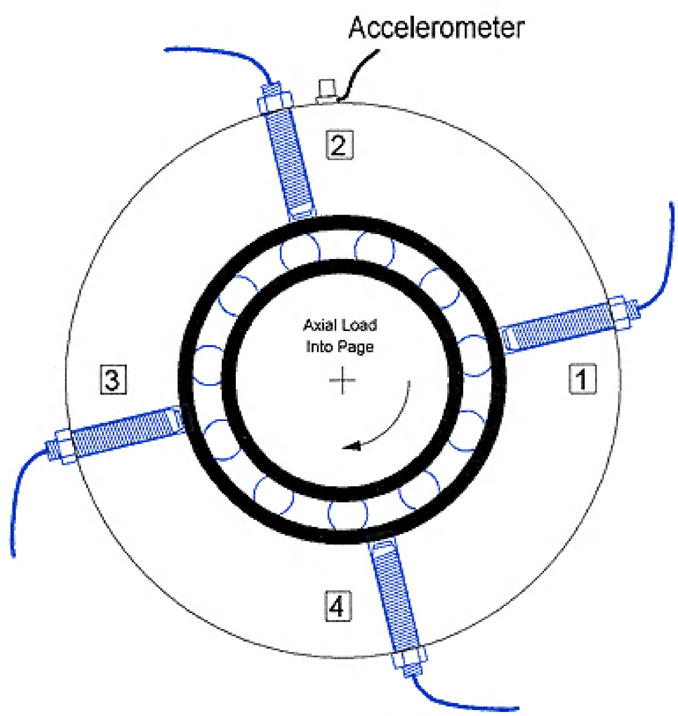


**Figure 1**
**Test bearing transducer layout**

bearing used in the axial load test was a Model 214 Conrad-type deep groove ball bearing. The bearing characteristic frequencies for this bearing at a shaft speed of 3550 rpm are:

Outer Race Element
Pass Component = 270 Hz
Inner Race Element
Pass Component = 381 Hz
Cage Rotational
Component = 24 Hz
2X Element Spin
Component = 336 Hz

The first step in the axial load failure testing was to collect some baseline data on a new bearing. This was later compared to the data from the bearing after spalling had occurred. Under axial loading, this baseline data showed the signal levels from all of the REBAM® channels to have a relatively linear increase with applied load. Axial loading produces an even distribution of element loading around the circumference of the bearing (provided symmetry in alignment, machining, etc., exists). Symmetry in the REBAM® signal levels was therefore expected. Channel 2, however, showed a slightly higher amplitude than the other three. Channel 4 showed a slightly lower amplitude. This is likely due to a small amount of residual radial load present. The center of the radial load zone is 22 degrees closer to the Channel 2 probe than Channel 4.

Another likely influence adding to this effect is residual radial loading causing "frictional loading" in the bearing. Radial loading causes frictional force interaction between the elements and the inner ring to put a force on the shaft in the direction 90 degrees from the center of the load zone (like road friction on an automobile's driven wheel which propels the car forward). In this case, this would be towards the Channel 2 REBAM® probe. This results in the center of the radial load zone being shifted further toward the Channel 2 probe. These two effects combine to produce the higher amplitude seen on Channel 2 and the lower amplitude on Channel 4. This is consistent with the amplitude characteristics seen in the radial load baseline data.

## Bearing failure under axial load

The next stage of testing was to achieve a fatigue spalling failure under axial loading. Using an identical test bearing (214 ball bearing) with a small stress concentration placed on the shoulder of the outer race where the contact line was expected to occur under high axial load, the bearing was run continuously under about 4000 pounds (17.8 kN) axial load. As with the bearing in the radial load testing, the stress concentration was placed in the outer race by electrostatic discharge. It was small enough that no indication of its presence showed on any of the signals (REBAM® or accelerometer). Spalling was expected to initiate in the outer race at the stress concentration which was near the Channel 1 probe.

After about 33 hours of operation at 4000 pounds (17.8 kN) axial load, all four REBAM® channels began to show negative spiking in the Timebase *once-per-shaft-rotation*. If spalling were beginning near the Channel 1 probe, we would have expected to see *once-per-ball-pass* spiking in the Channel 1 signal. Since it occurred once per shaft revolution, we suspected inner race spalling was developing instead.

In hindsight, there are two factors which support the likelihood of an inner race spall developing prior to outer race spalling under axial loading. First, the inner race ball pass frequency is higher than the outer race ball pass frequency. This causes a point on the inner race to see more loading cycles in a given time period than a point on the outer race which leads to faster material fatigue on the inner race. Second, the inner race element contact area is generally smaller than that of the outer race as the line of contact on the inner race is convex while the line of contact on the outer race is concave. A smaller contact area for a given element loading means higher stresses on the inner race, further reducing the fatigue life of the inner race material.

Why didn't inner race spalling occur first during the radial load failure test? The answer is that the inner race is unloaded during a portion of each shaft revolution under radial loading. This causes fewer loading cycles during a given time period (longer fatigue life). Under axial loading, the inner race is under load during the entire revolution.

Figure 2 shows the axial load failure progression as seen in the signal from the Channel 1 probe. The other three channels showed nearly identical failure progression patterns, with Channel 2 being slightly higher in amplitude. The spalling initially shows up as a relatively discreet negative spike once per shaft revolution. As the damage to the bear-

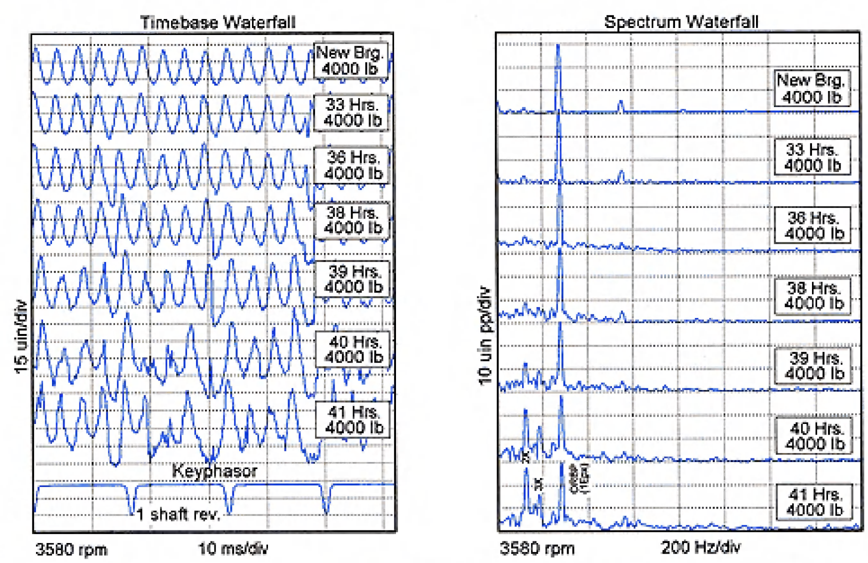


**Figure 2**
**Axial load failure progression as seen from the Channel 1 REBAM® probe**

**Figure 3**
**Inner race damage and element damage**

ing progresses, the spall area broadens, and we see a corresponding broadening of the spikes. Eventually, additional spalled areas show up on the inner race and some of the rolling elements. This makes the signal very complex, since spalling begins to coincide with contact points in a more random fashion.

From baseline to final spalling condition, the Channel 1 REBAM® signal shows an increase of approximately 125 percent. If we filter the signal into the Rotor Frequency Region (1/4X to 3X rotor speed) and the Prime Spike Frequency Region (1 to 7 times outer race element pass frequency), we see increases of approximately 1000 percent (yes, one thousand) and 100 percent, respectively. Remember that these amplitudes are from a particular bearing (214 ball bearing in this case); other bearing sizes and types would likely show different values. For example, a greater outer ring thickness would cause a higher stiffness of the material and produce a lower REBAM® signal level for a given amount of loading.

The Spectrum plots indicate the majority of change in the signal occurs in the lower frequency region below the outer race ball pass frequency. The frequency region below 3X shaft rotational speed is referred to as the Rotor Frequency Region since this is where rotor-related malfunctions (unbalance, misalignment, instabilities, etc.) would show up.

From this data, we can now say that inner race and/or element spalling will also show up in this region. In particular, the Spectra in Figure 2 show a large increase in the 2X and 3X components in the final four hours of axial load testing, probably due to additional areas of spalling developing on the inner race. For example, two diametrically-opposed inner race spalls would produce element contact with a spall near a given REBAM® probe twice per shaft revolution (2X); three would produce 3X, etc. After removing the test bearing and inspecting the races and rolling elements, enough damaged areas were observed on the inner race to produce this effect. Figure 3 shows the damaged test bearing from the axial load failure test. There was no visible spalling on the outer race.

As in the data from the radial load failure test, the data from the accelerometer during the axial load test shows excitation of structural resonances. Figure 4 shows the axial load failure progression as seen on the accelerometer. After 31 hours of testing, the accelerometer base loosened, so the data was therefore invalid between 31 hours and 41 hours. The Spectrum Waterfall plot in Figure 4 shows that the majority of the vibration energy is in two regions: one centered near 1450 Hz and the other near 4500 Hz. There is very little vibration down in the vicinity of the element pass frequencies. As in the radial load test, vibration energy at these lower frequencies was likely lost below the noise level of the accelerometer signal.

### Failure detection under realistic axial loading

Since the 4000 pounds (17.8 kN) of axial load used to fail this bearing was extreme compared to actual field service loading that this bearing might see, the next step was to determine how the bearing damage would appear under a realistic axial load. This same bearing, ►

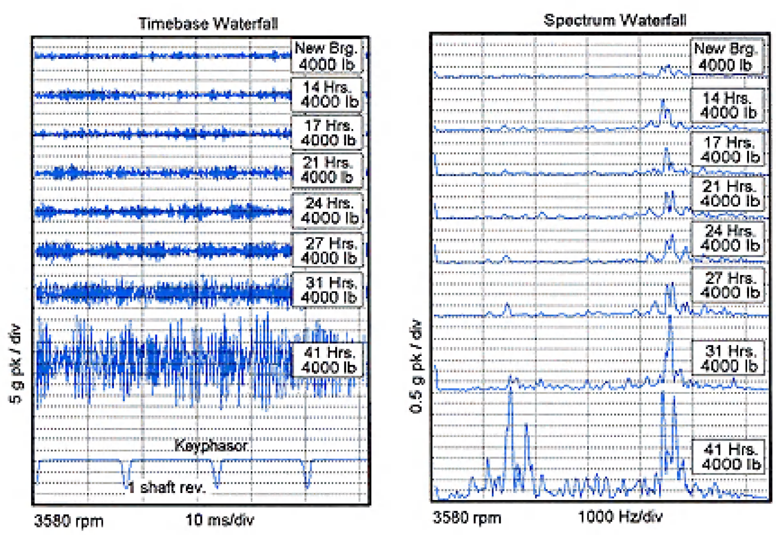


Figure 4
**Axial load failure progression as seen from Accelerometer**

damaged from the axial load failure test, was placed under 300 pounds (1.33 kN) of axial load, and the signals were compared to those on a new bearing under the same loading. Figure 5 shows the results in the Channel 1 REBAM® signal. It is clear that the outer race element pass component does not dominate the signal to the degree that it does under high axial load. The unfiltered amplitude of the signal increased from about 17 to 70 $\mu$in peak-to-peak (pp) (0.43 to 1.8 $\mu$m pp), a 310 percent increase. The Channel 1 signal filtered to the Rotor Frequency Region increased from 7 to 40 $\mu$in pp (0.18 to 1.0 $\mu$m pp), a 470 percent increase. The Prime Spike filtered region showed a 250 percent increase from 10 to 35 $\mu$in pp (0.25 to 0.89 $\mu$m pp).

Following the low load test at 3550 rpm, a low speed test was performed to determine how well the REBAM® System performs in low speed applications. The test rig speed was lowered to 78 rpm, and REBAM® and accelerometer readings were recorded for a new bearing and the same damaged bearing from the axial load failure test. Under 300 pounds (1.33 kN) of axial load, the unfiltered REBAM® signal from Channel 1 increased 360 percent from 15 to 70 $\mu$in pp (0.38 to 1.8 $\mu$m pp). The other three channels showed similar results. No dynamic signal was seen from the accelerometer on the new or damaged bearings. This was expected due to the low speed of the rotor.

## Conclusions

In review, Part 1 of this article (*Orbit*, September 1992) discussed radial load testing, and the following conclusions were drawn:

1. REBAM® probes which are mounted away from an outer race spall will likely show evidence of bearing damage when the spalling progresses to the inner race or elements.
2. The REBAM® system is best utilized as an indicator of when a bearing needs to be replaced. A seismic transducer (casing mounted accelerometer) is likely to give earlier warning of bearing wear, but may also cause the user to replace the bearing before it is economically optimum.
3. The REBAM® system provides a much clearer picture of what is occurring in a particular bearing than a seismic transducer.
4. A REBAM® probe which is mounted in the least optimum angular position (180 degrees from the radial load zone center) is still likely to give very good evidence of spalling in the bearing.

In this article, Part 2, failure testing under axial load, the lower axial load testing with new and damaged bearings, and the low speed axial load testing offer additional insight into the performance of the REBAM® system during ball bearing failures, including:

5. The REBAM® system effectively monitors ball bearings under axial loading.
6. If there is axial loading present, then the angular location of the REBAM® probe is likely unimportant, as loading occurs around the entire circumference of the bearing. Part 1 of the article mentioned that this was also true for this type of bearing under 300 pounds (1.33 kN) of pure radial load. Even though this loading produced no significant signal on Channel 3 (opposite the load zone), the eventual damage to the inner race and elements produced enough dynamic loading within the bearing to be observed in this location.
7. For ball bearings under pure thrust loading, the initial spalling is more likely to occur on the inner race than the outer race due to the higher contact stresses on the inner race.
8. Inner race and element spalling is likely to show most dramatically in the Rotor Frequency Region of the REBAM® signal.
9. The REBAM® system works much better than accelerometers on ball bearings in low speed applications.

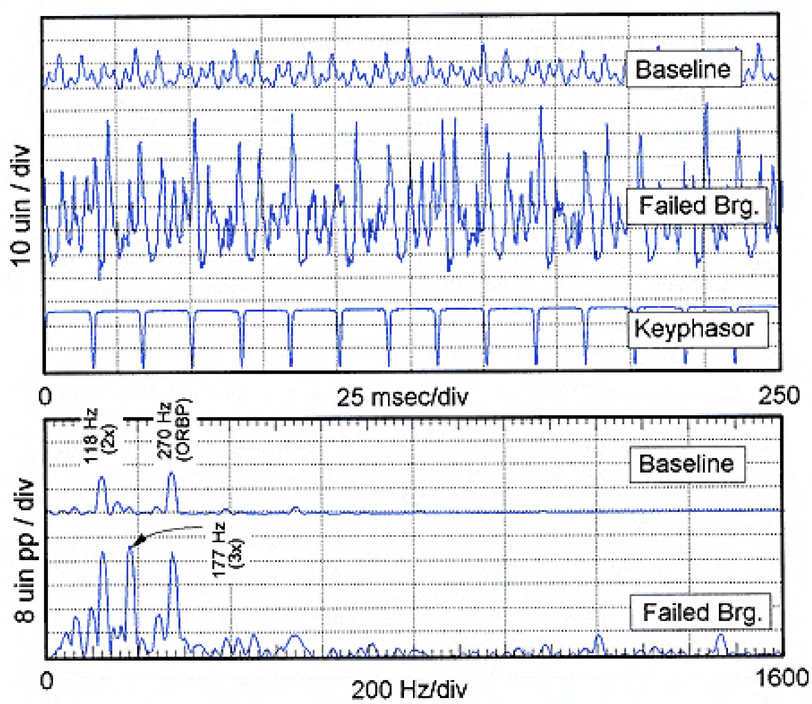


Figure 5
Baseline and failed bearing data under 300 lbs (1.33 kN) axial load as seen from Channel 1 REBAM® probe